CrIS Spectral Calibration

L. Larrabee Strow, Howard Motteler, Sergio De Souza-Machado, and Steven Buczkowski

UMBC
Department of Physics *and*
Joint Center for Earth Systems Technology

August 25, 2015

Overview

- JPSS-1 CrIS thermal vacuum (TVAC) spectral testing
- SNPP CrIS in-orbit spectral calibration performance
- SNPP CrIS Stability: three-year trends in CrIS radiances
- Mid-Wave Non-linearity in High Resolution Mode

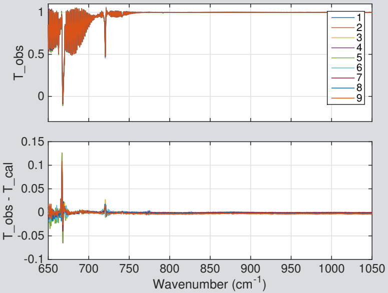
JPSS-1 CrIS Spectral Calibration in TVAC

- Spectral calibration has two components:
  - Absolute spectral calibration, provided by Neon lamp, which is calibrated in TVAC.
  - Apodization smearing of ILS due to off-axis detectors. Need accurate effective detector positions to correct, as determined in TVAC.
- Both Neon and focal plane geometry derived from analysis of gas cell spectra.
- 1 ppm accuracy requires modeling to $\sim$0.001 in transmittance!

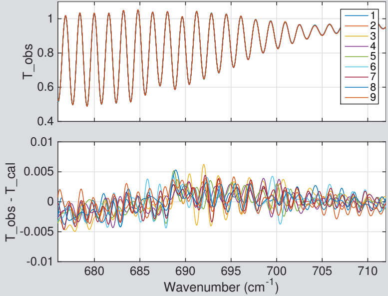
1 ppm accuracy keeps NWP bias correction standard deviation small enough (if using multiple FOVs).

LW CO_2 Spectra (MN, Side 1)

Full CO_2 Spectrum



Region Fitted

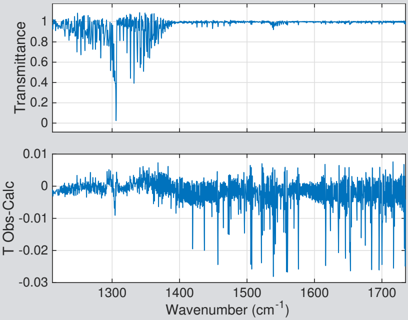


Observations

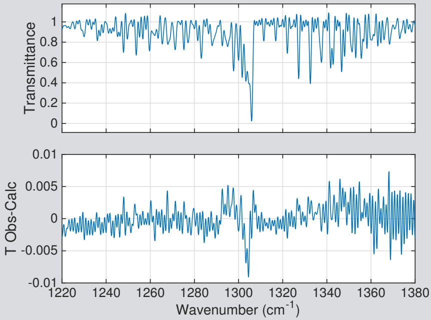
- Avoid CO_2 Q-branch region, spectroscopy limitation (in RTA too!). LBLRTM (AER) and kCARTA (UMBC) give similar results.
- Slight baseline shift near 687 cm^{-1}?

CH_4 Spectra

Full Spectrum (H_2O contamination)



Region Fitted

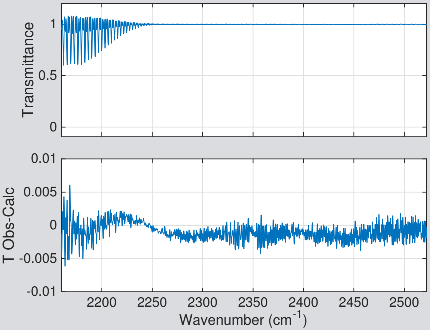


Observations

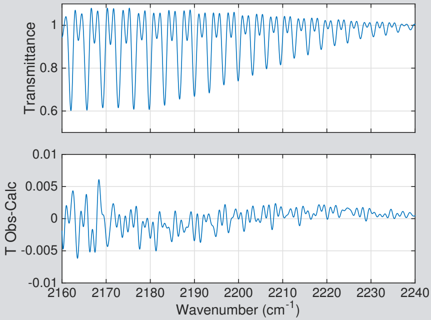
- Avoid water vapor contamination
- Small amount of Q-branch line-mixing evident near 1300 cm^{-1} (can be ignored in fit).

CO Spectra

Full Spectrum



Region Fitted



Observations

- Minor baseline oscillation, should average out.
- Spectroscopy better here than in long-wave or short-wave

Test Summary

Δ Neon (from FM-1) = 2.8 ± 0.2 ppm or 703.45036

Test ID	T	Side	Neon (ppm)	P_log (torr)	P_fit (torr)	fit-log (torr)	Lien
11-20_CO2	PQL	1	-1.8	41	22	-19	Bad P
11-25_CO2	PQL	2	0.5	40	27	-13	Bad P, 775 cm-1?, Fringes
10-16_CO2	MN	1	3.1	40	40	0	
10-18_CO2	MN	2	3.9	40	40	0	Fringes
11-09_CO2s1	PQH	1	4.6	40	40	0	NH3, Fringes
11-09_CO2s2	PQH	2	2.6	41	37	-4	NH3, Fringes
11-20_NH3	PQL	1	6.0	20	18	-1	FOV9 way off
11-19_NH3	PQL	2	3.9	21	18	-3	
10-16_NH3	MN	1	3.6	39	37	-2	
10-27_NH3	MN	1	12.1	21	40	19	Bad P
10-18_NH3	MN	2	11.9	40	6	-34	Bad P
11-09_NH3	PQH	1	12.6	20	34	14	Bad P
09-27_NH3	PQH	2	10.8	39	7	-32	Bad P
11-20_CH4	PQL	1	2.1	41	30	-12	Bad P
10-16_CH4	MN	1	2.8	40	40	0	
10-18_CH4	MN	2	2.6	42	42	-0	
11-05_CH4	PQH	1	2.8	41	41	0	
11-19_CO	PQL	1	2.6	45	45	0	
10-15_CO	MN	1	3.1	42	42	0	
10-18_CO	MN	2	2.6	41	41	0	
10-02_CO	PQH	1	3.1	40	26	-14	Bad P

PPM Errors (ShortWave Example)

Uncorrected ν Offsets

520	370	520
370	0	370
520	370	520

x,y offset Correction

-17	-12	-17
-12	0	-12
-17	-12	-17

Error after x,y Adjustment (SW)

-1.2	-0.7	-2.3
-1.0	0	0.2
-1.6	-0.8	-1.7

Error after δr Adjustment (SW)

0.2	0.3	-0.9
0.0	0	1.2
-0.2	0.1	-0.3

Only 3 numbers needed to nearly reach 1 ppm!

For all three focal planes max error = 2.8 ppm, only 6 detectors needed adjustments to keep errors below 1 ppm.

All detector placements relative to interferometer axis driven to zero in Engineering Packet data.

JPSS-1 TVAC Conclusions: Spectral

- Focal plane detector positions determined to 1 ppm
- Neon calibration determined to 1 ppm, only 2.8 ppm difference from SNPP (probably alignment)
- Excellent fits to gas cell data

Recommendations

- Delete NH_3 tests: not successful and not needed!
- Substitute with longwave test with gas cell filled with CO_2 broadened by air. These are fabulously accurate spectra, this will help NWP assimiation via an improved RTA in region not easy to bias correct.

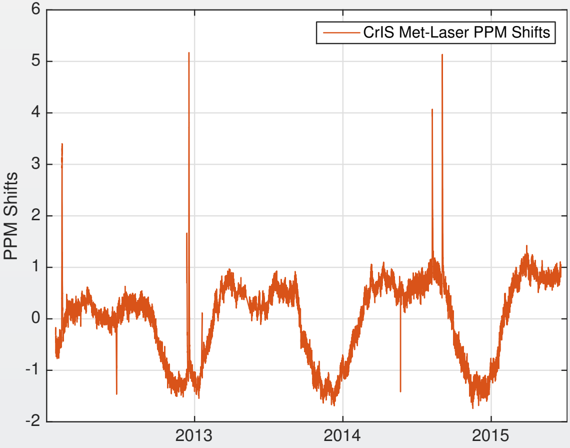
SNPP In-Orbit Spectral Calibration

- Concentrate on stability
- Post-launch modifications:
  - Focal plane x,y offsets adjusted
  - Slight change to radius (gravity release of telescope)
  - Neon unchanged
- Neon lamp drifts (emission geometry) main possible source of spectral calibration drifts.

Approach

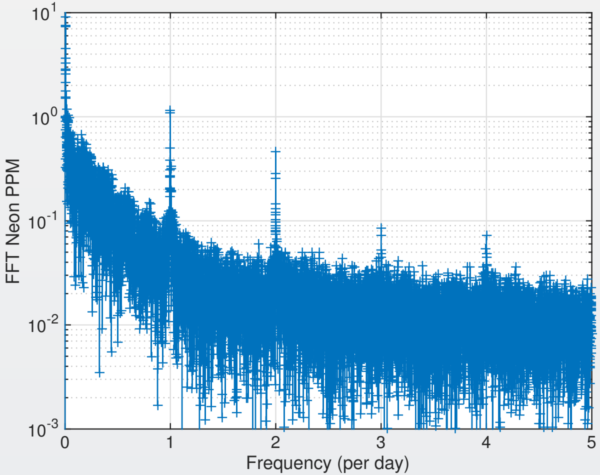
- Neon calibration determined from clear tropical up-welling spectra vs simulations using cross-correlation.
- CrIS SDR produced by IDPS only tracks Neon to 2 ppm.
- Consequently, cannot use IDPS SDRs to track Neon calibration.
- This Work: re-processes full mission SDRs with UW/UMBC CCAST SDR testbed, follow the Neon at all times.
- CCAST algorithm used is one of two approaches under consideration for JPSS-1.

Metrology Laser Shifts a/c to Neon Lamp



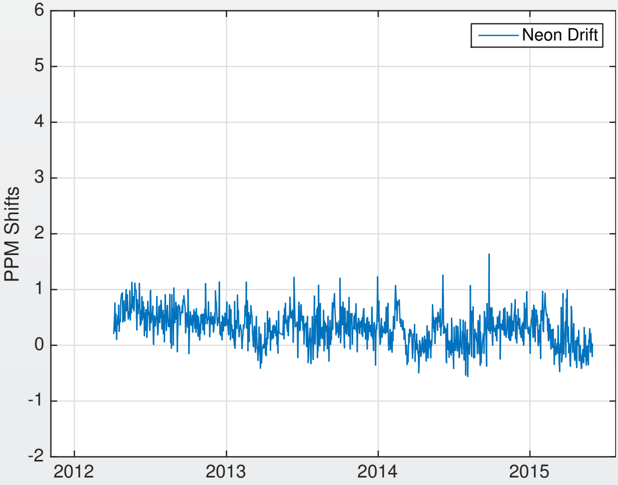
This is possibly to due with the thermal control of the metrology laser being impacted by the external IR radiation environment.

Fourier Analysis of Neon Time Series



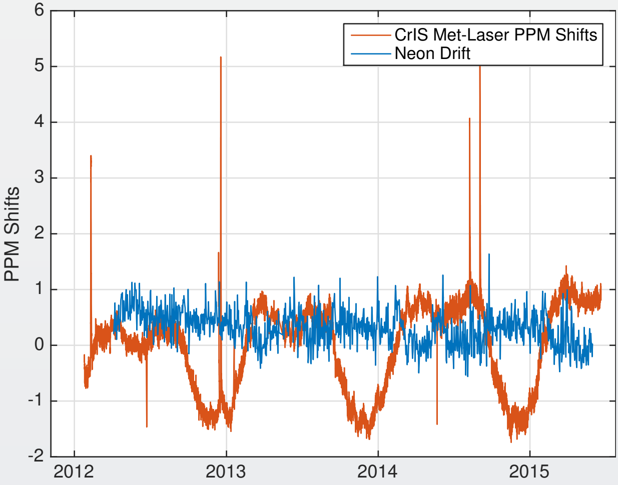
Hash on previous slide is the 1-day cycle seen here. Albedo effect on metrology laser wavelength?

Neon Drifts from Upwelling Radiances



This is a once/day measurement from clear tropical ocean scenes.

Neon Drifts from Upwelling Radiances

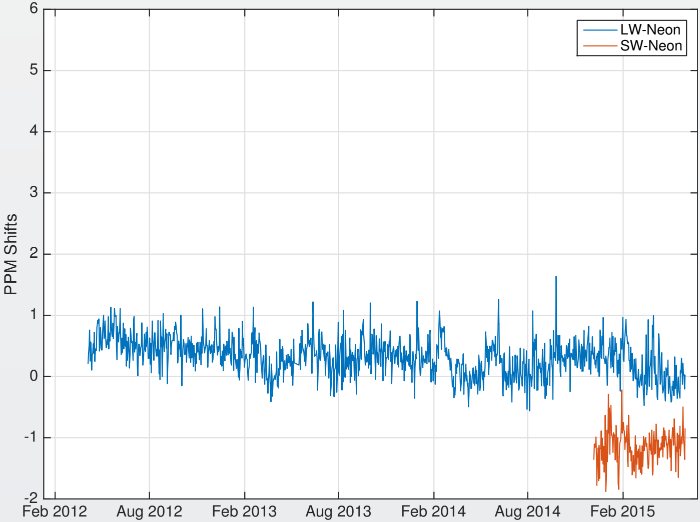


This is a once/day measurement from clear tropical ocean scenes.

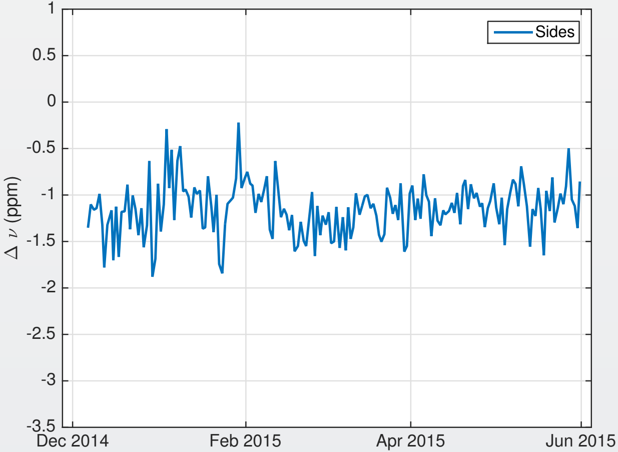
Conclusions: SNPP CrIS Neon Stability

- Most of variability in the metrology laser wavelength is real.
- There may be a slight drift in the Neon wavelength.
- A linear fit to the derived Neon wavelength gives -0.13 $\pm$0.12 ppm/year. Possibly a 0.5 ppm change since early 2012.
- For NWP assimilation, these drifts may be removed with dynamic bias correction.
- They are identical for all 9 FOVs.

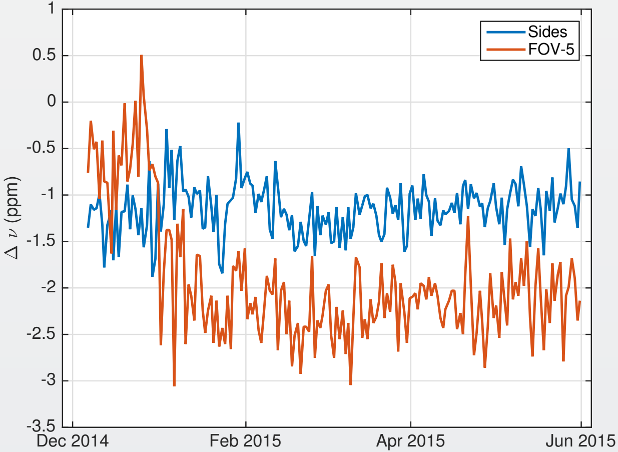
Neon Calibration using High-Res CrIS Radiances



Neon Calibration using High-Res CrIS Radiances



Neon Calibration using High-Res CrIS Radiances

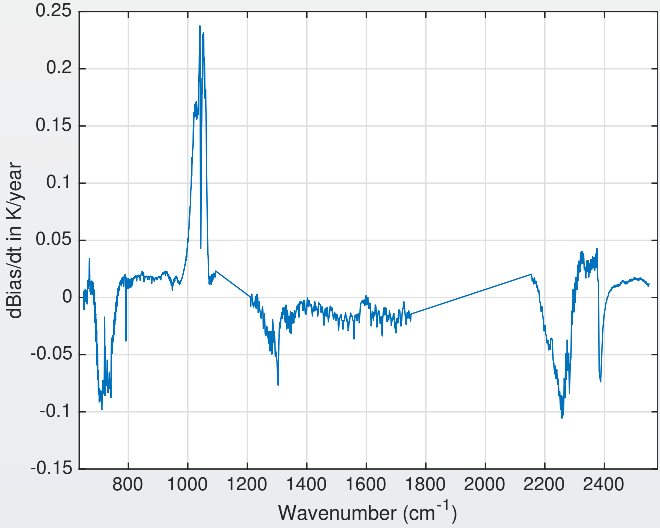


2.5 ppm shift in FOV-5 at end of December??

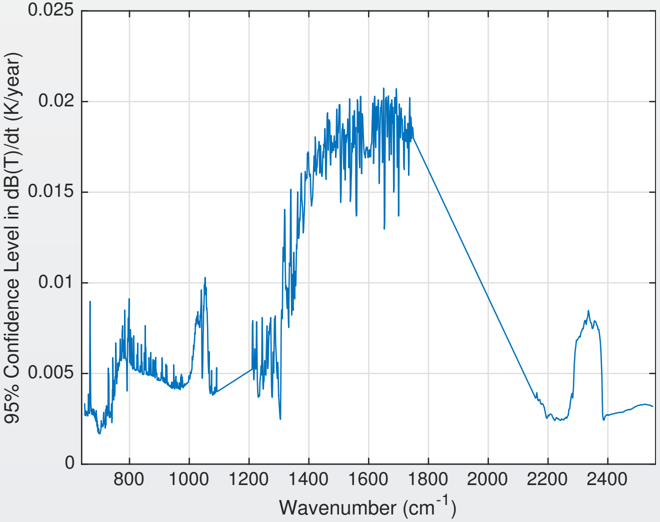
Estimation of CrIS In-Orbit Stability: Approach

- Start with CCAST processed SDRs (stable algorithm)
- CCAST converts to normal-resolution post Dec. 2015
- Subset for clear, ocean tropical scenes (uniformity filter)
- Match each scene of ERA Interim re-analysis and compute simulated radiance
- Create daily average of observed and simulated radiances (365 x 3) long time series.
- Fit time series bias (Obs-Simulated) for linear rate (and seasonal terms).
- Perform an Optimal Estimation retrieval on bias time series (d(bias)/dt) spectrum to determine geophysical time derivatives. (O_3 is only column offset.)

CrIS Linear B(T) Bias Rate over Three Years



2-σ Uncertainty in CrIS Linear B(T) Bias Rate



OE Fit Results

Units are all **per year**

CO2 (ppm)	2.35 +- 0.008	Full rate
O3 (%)	-1.22 +- 0.006	Relative to ERA
N2O (ppb)	0.82 +- 0.014	Full rate
CH4 (ppb)	7.79 +- 0.182	Full rate
CFC11 (ppt)	0.10 +- 0.016	Full rate
SST (K)	0.016 +- 0.000	Relative to ERA

Comparison to In-Situ for CO_2

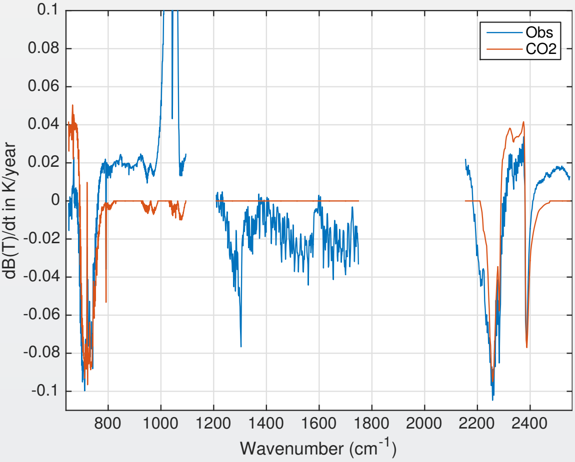
- NOAA/ESRL Global Mean CO_2 Rate for 2012-2014: 2.25 ppm/year
- CrIS - ESRL = 0.1 ppm/year implies CrIS stability of 0.005K/year.

Comparison to In-Situ for SST

- ERA SST is a measurement: GHRSST
- CrIS - ERA = 0.016K/year

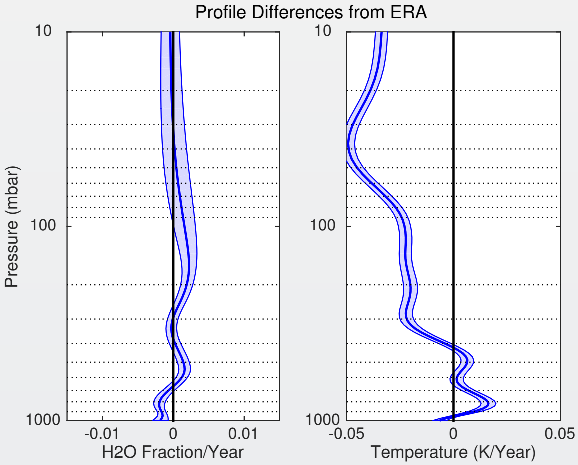
NOAA/ESRL CH_4 from 2012-2015 varies from 5-10 ppb/year

CO_2 Contribution to Spectral Bias



Issue in stratospheric sounding channels, we should differ from ERA by 0.04K/year! Could ERA not be able to bias correct for CO_2 in the upper strat?

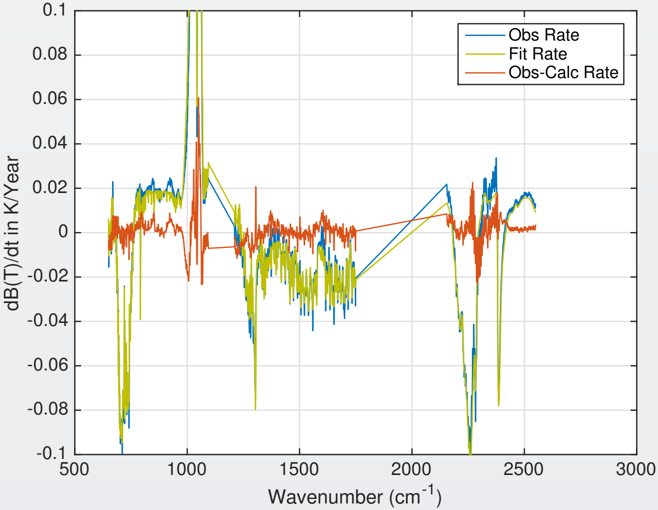
OE Profile Differences from ERA



For these altitude it is difficult to find a standard for temperature bias correction? Or is the CO_2 rate not constant with altitude?

Fit Residuals

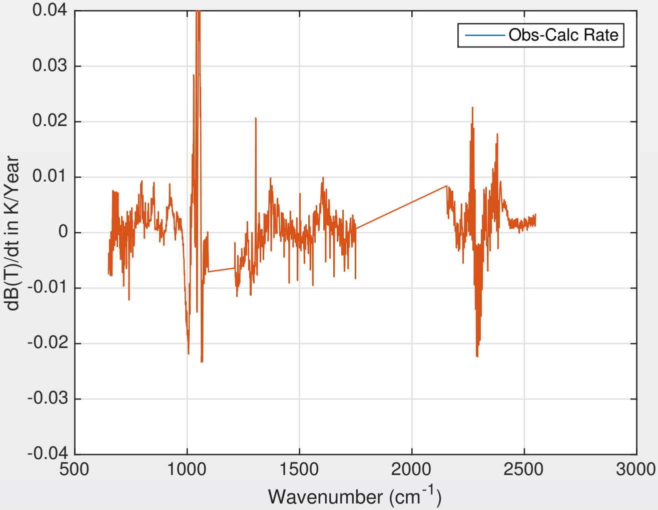
Requirements for Inter-Instrument Agreement



How well can we fit CrIS radiance time derivatives?

Fit Residuals

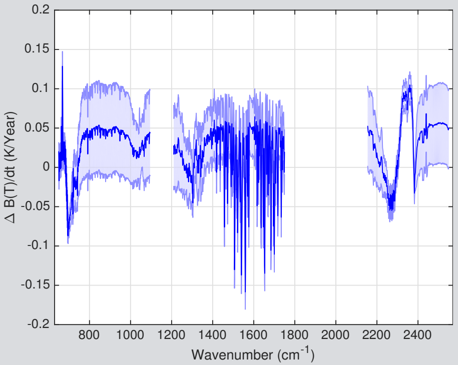
Requirements for Inter-Instrument Agreement



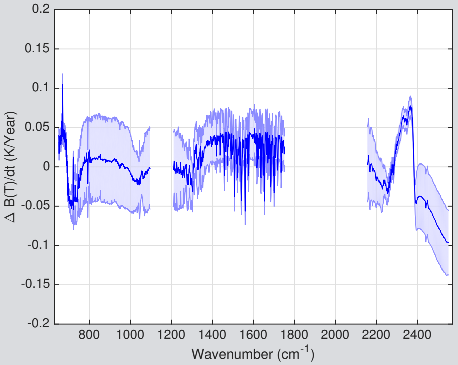
How well can we fit CrIS radiance time derivatives?

Globally Averaged Changes in CrIS B(T)

dBT/dt Night with 95% Uncertainty



dBT/dt Day with 95% Uncertainty

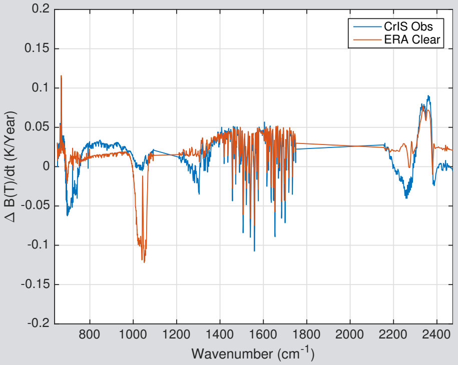


CO_2 forcing well defined (low uncertainty). Cloud and surface temperature response highly variable, need longer time span to lower uncertainty.

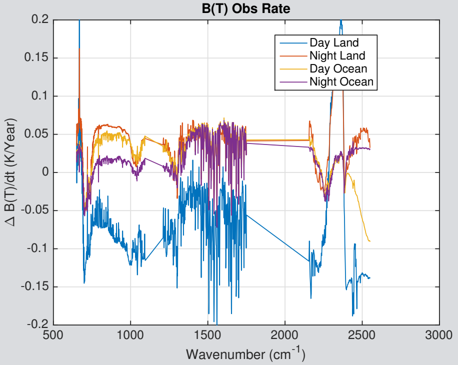
CrIS Global Δ B(T)

Versus ERA-Clear and Binned by Day/Night/Land/Ocean

Day + Night dBT/dt: Obs, ERA-Clear



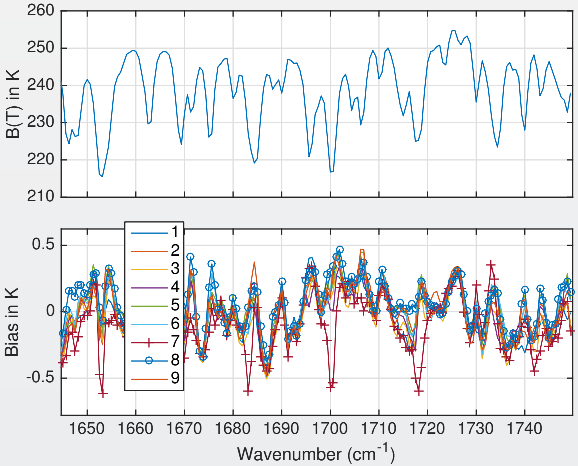
dBT/dt: Day/Night/Land/Ocean



ERA global (day + night) clear sky linear rate very close to CrIS observations (except for minor gas forcings).

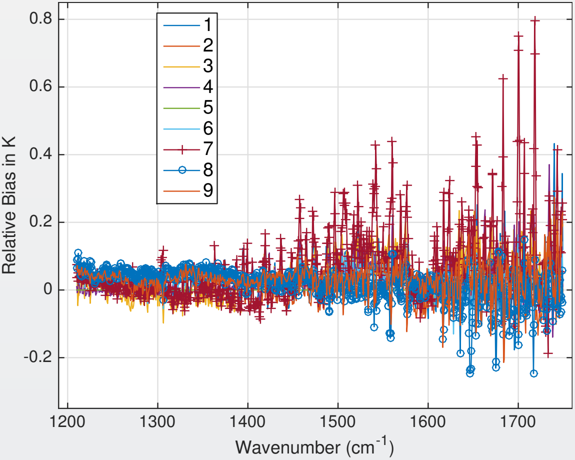
Day, Land rates very different from others. Day ocean suggests increasing clouds.

Mid-Wave Non-Linearity in High-Resolution Mode



Tropical clear bias vs ECMWF, Hamming apodized high-spectral resolution radiances from CCAST.

Mid-Wave Non-Linearity in High-Resolution Mode



Same as prevous slide, but now subtracting all biases from FOV-5 bias.